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Larger Packages Fuel Thermal Strategies

The trend toward surface-mount assembly processes is making ball-grid array (BGA) packaging a popular choice for many types of devices, forcing designers to re-examine cooling of these large packages. While devices in BGAs transfer more heat to the board than leaded devices, the style of BGA packages has a large influence on the ability to transfer heat through other pathways, such as a top-mounted heat sink. Physical characteristics of the BGA further constrain the thermal designer. It takes forethought in board design to successfully accommodate devices that require significant heat dissipation. Multiple solutions exist, however, for BGA packages of all types.

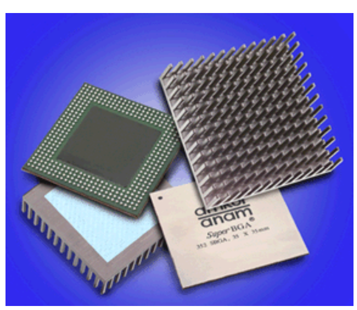
Leaded packaging such as quad flat packs (QFPs) can no longer accommodate the high I/O levels required by many of today's integrated circuits. Between pin counts of 208 and 260, QFPs reach the maximum reliable bond length, and assembly becomes cost prohibitive. In the early 1990s, Motorola Inc. introduced what would come to be called the plastic ball-grid array (PBGA), a package that replaced the traditional gull-wing style leads with eutectic solder balls that sit directly under the IC package. This package style easily accommodates more than 260 I/O points, while improving other aspects of IC attach, with few drawbacks. PBGA and similar packages such as ceramic BGAs—collectively referred to as BGA packages—offer significant space savings over QFPs: a 225-ball PBGA takes up half the space of a 208-lead QFP.

The large array of solder balls under the IC provides considerable heat transfer away from the device, dissipating as much as 4 W without a separate heat sink. While this is a significant improvement over QFPs, the selection of a BGA package type can greatly affect the ability to dissipate sufficient heat to maintain high device reliability. All-plastic packages insulate the top of the device, making heat dissipation through top-mounted heat sinks more difficult and more expensive. Metal heat spreaders incorporated into the top of the package enhance the ability to dissipate power from the chip.

The insulating properties of the all-plastic BGA packages require heat dissipation from more of the package surface area to perform the same cooling. The rough surface of the plastic, and the often irregular shape, require the use of gap-filling interface materials. These materials, although designed for optimum thermal transfer, reduce the effectiveness of the heat sink because they do not transfer heat as well as a direct surface connection between the heat sink and the package. To improve the transfer, a cavity is machined into the heat sink, allowing contact with more of the package surface area. The machining process alone increases the cost of the heat sink by as much as $3 to $4 over conventional heat sinks.

With so-called "glob-top" style packages, up to 40 percent of the package surface is taken up by the irregular glob, exacerbating the problem with gap filling and increasing the amount of machining required.

Several manufacturers incorporate heat spreaders into their BGA packages. The heat spreader is in direct contact with the integrated circuit, and is integrally molded into the package. When a heat sink is required, it can be attached directly to the heat spreader, either through physical mounting devices such as screws or clips or through a double-sided thermal tape, with no need for gap filling. On the down side, these types of packages—SuperBGAs or high-performance BGAs—are more expensive than the original all-plastic package. For devices that need additional cooling, however, using a more-expensive package with a less-expensive heat sink may reduce the overall system cost. Up-front thermal modeling can determine whether additional cooling is required.



Super BGA and i960 shows micro pin array and i960™ is a micro controller used in embedded systems.

As the requirement for heat dissipation increases, so does the weight of the heat sink. In applications with significant shock and vibration, this weight can cause strain on the solder balls, potentially shearing the electrical and physical connection of the package to the board. To reduce the reliability concern associated with ball shear, designers can attach larger heat sinks, dissipating more than 8 W, directly to the circuit board using clips, screws or specially designed spring-loaded pins. The clips and pins typically require additional holes in the printed-circuit board, further demonstrating the need for incorporating thermal modeling into the early stages of board design.

The complexity of devices that require BGA packaging usually means that they are expensive. To maintain costs, the system manufacturer needs to be able to remove a device that's malfunctioning due to improper solder connection or some other cause, and reinstall a working one. The attachment method used to fit the heat sink to the device can have a direct impact on repairability. Adhesives, for example, permanently bond the heat sink to the device. If the heat sink extends over the edges of the package, it becomes difficult, if not impossible, to remove the device from the board. Spring-loaded clips, on the other hand, make it easy to do so, providing direct access to the BGA for repair.

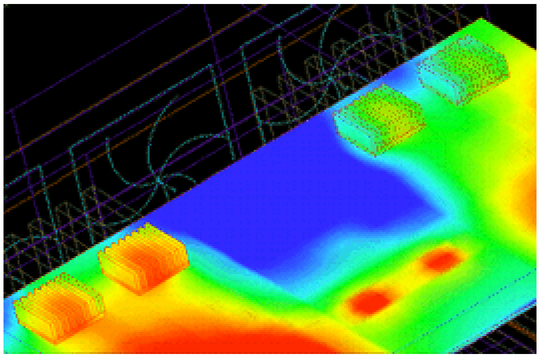
Whether modeling suggests that a small amount of cooling is required, or whether this is determined after the fact from an overheated chip, thin copper spreaders provide additional heat removal for devices dissipating 2 to 5 W. A lightweight extruded heat sink, using crosscut fins, is useful for devices dissipating 3 to 8 W. These lightweight heat sinks attach using preapplied double-sided tape. While these low-cost examples are easy to assemble, reduced repairability may make it worthwhile to find an alternative.

Heavier, extruded heat sinks offer customized cooling at an off-the-shelf price. As long as the weight of the heat sink is not borne by the ball array, this solution offers the advantage of long-term reliability with easy repair. Extending the heat sink beyond the edge of the package allows direct connection to the printed-circuit board, eliminating stress on the ball array. Clips, screws or spring-loaded pins can attach the heat sink to the board, while providing sufficient contact with the spreader on the BGA package to ensure good thermal transfer. Large-volume ICs with standardized platforms warrant the design of specialized clips to hold the heat sink in place.

The initial cost to produce these clips limits their use in low-volume applications—the die used to manufacture them can run as much as $30,000. Plastic clips that contact the underside of the chip may reduce the tooling costs associated with custom design, but the potential for electrostatic discharge prevents large-scale usage. For lower-volume applications, spring-loaded pins work well. Some heat-sink manufacturers recommend the use of double-sided tape with large heat sinks, but this may reduce reliability.

Multiple BGAs

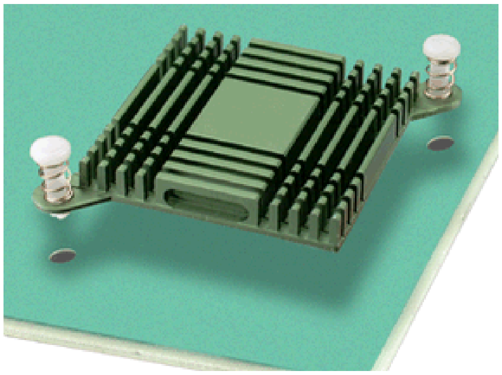
When designers start looking at cooling for multi-BGAs, one key is that thermal transfer to the air will decrease across the array, regardless of the board layout and cabinet design. Data communications and network routing and switching systems often use large arrays of identical devices with BGA packaging. These arrays demand attention to other thermal issues, but also offer some advantages in heat-dissipating strategies. In many cases, an identical operating temperature for the entire array of devices will produce the highest-quality system with the highest reliability.



Computational analysis shows that airflow is not uniform; some chips will be hotter than others when the same heat sink is used.

This requirement necessitates the use of heat sinks of multiple sizes. As air flows across the array, it picks up heat, changes direction and becomes turbulent, reducing the efficiency of thermal transfer from the device. Thus, chips in the array closest to the source of airflow will require a smaller heat sink than chips farther away.

Once the air pattern has determined the sizes of the required heat sinks, the space available for them must be evaluated. Often, the arrays are tightly packed to gain speed and reduce board space. The tight spacing may squeeze out space available for heat-sink mounting holes. The solution reduces assembly and rework costs. Heat-sink manufacturers will custom-design a single heat sink that cools all the devices in the array. The heat sink includes pedestals or cavities to accommodate each device. Gap-filling compound takes out tolerance mismatches between the heat sink and the BGA package itself.



Snap-in, push pin heat sink, with outboard pins.

This oversized heat sink attaches at the outer edges, with a spring-loaded pin connection in the center of the board for very large or heavy heat sinks. A single, large heat sink takes less time to install than individual heat sinks, cutting assembly cost. And it will also take less time to remove, easing field repair.